A cold-climate tertiary treatment wetland: Summary of four years of water quality data at the Southwest Licking County (OH) wetland

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Introduction

The use of wetlands to treat domestic wastewater is a common practice in many parts of the world (Mitsch and Gosselink, 1993; Kadlec and Knight, 1996). Attention first focused on using natural wetlands (peatlands, swamps, and marshes) to treat wastewater (Odum et al., 1977; Fetter et al., 1978, Kadlec and Tilton, 1979; Dierberg and Brezonik (1984, 1985); Knight et al., 1987). Since then, attention has focused on the construction of wetlands to treat wastewater primarily because natural wetlands are scarce in many parts of the world and are now protected by a number of laws and regulations. There are now hundreds of documented constructed wastewater wetlands in North America and Europe. Results of many of the North American constructed wetlands have been summarized in a data base maintained by the USEPA. Summaries of those data are given by Kadlec and Knight (1996).

Generally, constructed treatment wetlands are designed for either surface flow over the substrate or subsurface flow through a substrate. Surface flow wetlands, though generally less effective in removing some pollutants at first, are closer in design to natural wetlands. Their other main advantage is that they are less prone to clogging and therefore require less maintenance. Subsurface flow through artificial wetlands can be through soil media (*root-zone method*) or through rocks or sand (*rock-reed filters*) with the flow in both cases 15 to 30 cm below the surface (Wieder et al., 1989). In a survey of several hundred wetlands built in Europe for sewage treatment in rural settings, Cooper and Hobson (1989) report that gravel is used in combination with soil, but that the substrate remains the greatest uncertainty in artificial reed (*Phragmites*) wetlands in Europe that are used for water quality enhancement. Constructed wetlands with subsurface flow have the advantage of requiring smaller area for the same retention of chemicals but they are prone to clogging if overloaded.

The nutrient retention capacity of wastewater wetlands has been well documented (reviewed by Kadlec and Knight, 1996). A hypothetical nitrogen mass balance developed by Kadlec and Knight (1996) for a moderately loaded wastewater wetlands shows that wastewater wetlands are capable of routinely removing 100 to 300 g-N m^{-2} yr^{-1}, a rate much higher than wetlands used for nonpoint source pollution control. Kadlec and Knight (1996) point out that the role of vegetation uptake in the nitrogen budget is not trivial and can be 25% or more of the retention. However, only a fraction of that nitrogen is permanently buried in the sediments. Both the rates of nitrification and denitrification greatly exceed the rates that would be estimated from only a water quality inflow-outflow analysis. Kadlec and Knight (1996) estimated that the true rate of denitrification in wastewater wetland, based on rate constants rather than water quality analyses, is on the order of 280 g-N m^{-2} yr^{-1}, a rate far in excess of those estimated for most natural wetlands and riparian forests.

Table 1 summarizes nitrogen removal efficiency of wastewater wetlands from the North American data base. Removal efficiencies range from 44% nitrate removal for constructed surface flow treatment wetlands to 77% for natural surface flow wetlands. Removal rates of nitrates ranged from 13 to 547 g-N m^{-2} yr^{-1} with the low number for constructed surface flow wetlands and the high number for

Table 1. Nitrate and total nitrogen removal rates and efficiency of natural and constructed wastewater wetlands as averaged from a number of systems in North America. From Mitsch et al. (1999) as adapted from Kadlec and Knight (1996).

Wetland Type	Nitrate + nitrite N					Total N				
	In mg/L	Out mg/L	LR g m^{-2} yr^{-1}	RR g m^{-2} yr^{-1}	Eff. %	In mg/L	Out mg/L	LR g m^{-2} yr^{-1}	RR g m^{-2} yr^{-1}	Eff %
Natural wetlands	4.30	0.29	52	40	77.5	10.2	2.3	96	69	71.9
Constructed wetlands										
Surface flow	1.90	1.21	29	13	44.4	8.08	4.58	277	126	45.6
Subsurface flow	109	94.5	5767	547	9.4	41.4	12.1	1058	569	53.8

In = inflow concentration; Out = Outflow concentration; LR = loading rate; RR = removal rate; Eff = removal efficiency

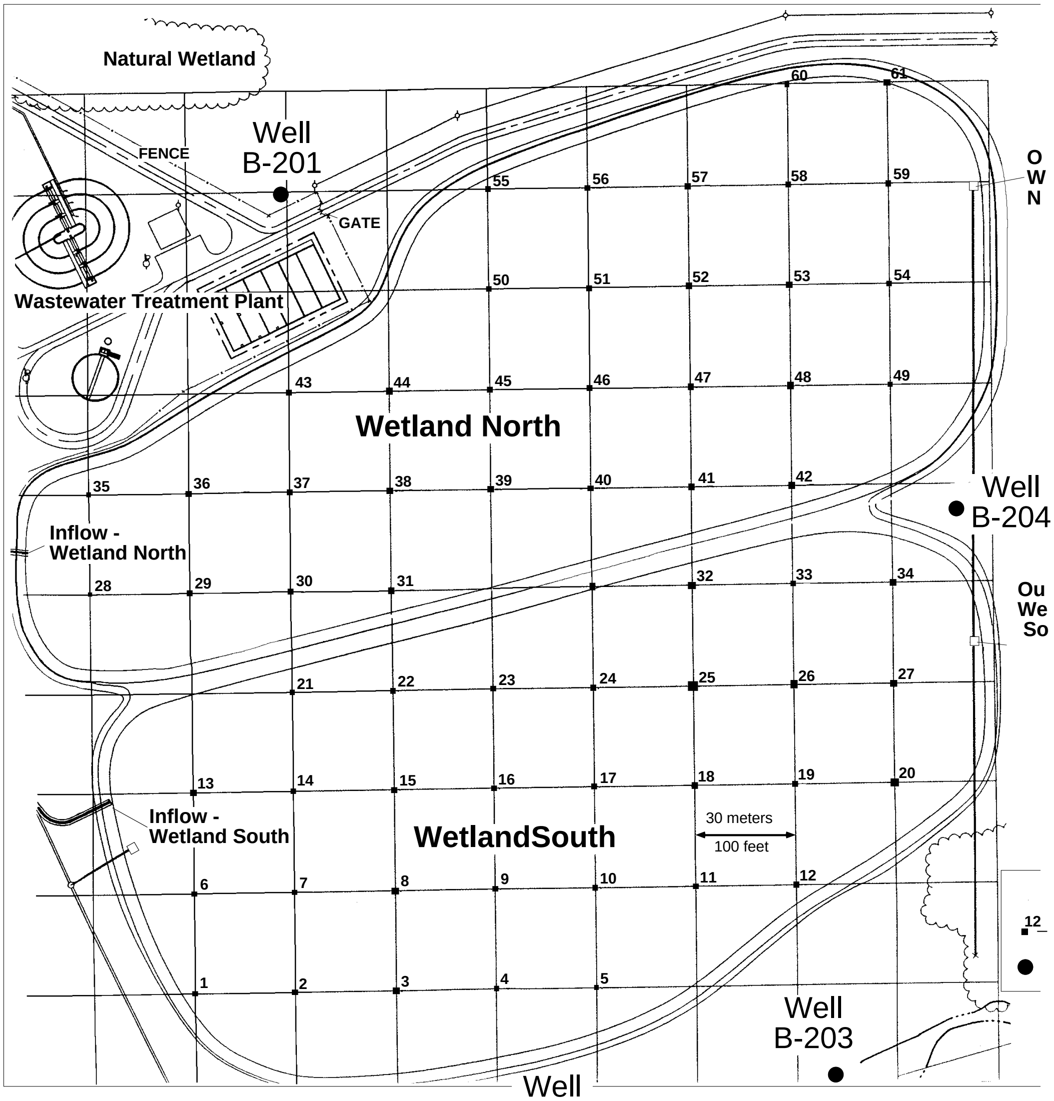

Figure 1. Licking County wastewater wetland basins as constructed in 1996. Only Wetland North is discussed in this paper. Wetland South was used only sparingly in 1996. Wastewater treatment plant is in the upper left hand corner.

constructed subsurface wastewater wetlands. These rates are in excess of what occurs in natural wetlands where nitrogen retention rates are generally in the range of 0 to 40 g-N m^{-2} yr^{-1}. (Mitsch et al., 1999). The high rates of nitrogen removal that are possible with constructed wetlands treating domestic wastewater suggest that these systems are efficient alternatives for controlling nitrogen from point sources. The generally lower costs of these wastewater treatment wetlands as alternatives to the more costly environmental technology add to their desirability as nutrient control systems.

This paper presents results of four years of research at one of the first surface water wetlands constructed for tertiary treatment in Ohio. We investigate the original goals of the constructed wetland, namely 1) to reduce nitrogen, especially nitrate, loading, to the South Fork of the Licking River; 2) to reduce phosphorus loading to the river; and 3) to investigate wetland water quality enhancement in Ohio climatic conditions. The objectives of the project also included construction of an aesthetically pleasing wildlife habitat with a minimum of site maintenance. The site has been used as a location for wetlands research by The Ohio State University since 1995.

Methods

Site Description

The wetland complex, part of the Southwest Licking Community Water & Sewer District's wastewater treatment plant near Kirkersville, Ohio, was constructed in 1995. Originally two 3-ha (8-acre) wetlands were constructed as tertiary treatment systems for additional water quality improvement of secondarily treated wastewater before the water is discharged into the South Fork of the Licking River (Fig. 1). After one wetland (Wetland South) proved to be unreliable in retaining water in 1996, all wastewater was routed to Wetland North for the duration of the study. It is that wetland that is discussed in this paper. The wetlands were considered experimental in nature by the Ohio EPA and the existing permit allows discharge of the wastewater treatment plant effluent directly to the river in times of emergency.

Hydrology

Surface flows were monitored with rectangular weirs installed at the inflows and outflows of the two basins. Concrete weir boxes were installed at the outflows of both wetlands during basin construction. Each box supports three rectangular weir plates which can be adjusted to regulate the outflow and water level of the respective basin. A staff gage and Stevens water level recorder were installed at the outflow weir boxes to allow continuous measurement of surface outflow. A single rectangular weir, staff gage, and water level recorder was also installed at the inflow of during the spring of 1996 to measure surface inflow. Subsequent investigation of the inflow data suggested that the weirs were overestimating inflow so some inflow data for the wetland reported in this study are from daily treatment plant flow measurements.

Water Quality

Water samples were taken weekly at inflow and outflow of the wetland basins. A Solomat 520C meter, a Hydrolab H20G water quality meter, and a YSI probe were used to measure temperature, dissolved oxygen, conductivity, pH, and redox in the wetlands over more than 4 years of study. Water samples were taken to the lab at Ohio State where subsamples were filtered and frozen for later measurement of soluble reactive phosphorus. Unfiltered samples are preserved with concentrated H_2SO_4 (1ml/liter sample) and frozen for later analysis of total phosphorus and nitrate+nitrite (NO_3+NO_2). Sample preparation and preservation is completed within 48 hours of original collection. For all laboratory analyses, Standard Methods for the Examination of Water and Wastewater, 17th Edition (APHA, 1989) and EPA Methods for Chemical Analysis of Water and Wastes (US EPA, 1983) are followed. Both total phosphorus and soluble reactive phosphorus methods employ the ascorbic acid and a molybdate color reagent method (Method 424, Standard Methods). Turbidity was measured shortly after field sampling using a Hach 18900 Ratio turbidimeter. For soluble reactive phosphorus and total phosphorus, a Lachat automated system and Lachat methods (US EPA, 1983) are utilized. Total phosphorus samples are first digested by adding 0.5 ml of 5.6 N H_2SO_4 and 0.2 g NH_3SO_4 to 25 ml of sample and exposing the samples to a heated and pressurized environment for 20 minutes in an autoclave. NO_3+NO_2 was measured using a Solomat 520C monitor and an Orion ion selective electrode (Method 418B, Standard Methods) with the low detection limit of 0.5 mg-N/l and two ranges spanning 0.5 - 100 mg-N/l until July 9, 1997. After then, the Lachat system was used to determine NO_3+NO_2 through a flow-injection cadmium reduction technique.

Quality Control/Quality Assurance

All equipment used for monitoring in the field is calibrated either weekly, or immediately before being taken out to the field. Records of this calibration are kept in the Analytical Ecology Laboratory of The Ohio State University.

QA/QC (applies to phosphorus, NO_3+NO_2, and turbidity) samples interspersed throughout the runs were not to exceed in covering more than ten percent of the run. QA/QC values recovered could not vary by more than 10 % of true value or a re-run of that sample would be necessary. Analysis of the lab's distilled water were run at a minimum of every 10 samples. This qualifies the equipment, the chemistry involved, and the water produced in the lab. To every tenth sample, a know amount of standard was added. The values alternate from high to low concentrations to cover the range of the curve. After subtracting out the sample value, a percent recovery of the spike is calculated. The purpose of this is to demonstrate that there is no gross form of interference in the sample. To assure repeatability, one out of every ten samples is run in duplicate. QC standards were run following every spike, rotating between different ERA (Environmental Resource Associates) QC dilutions and distilled water spikes. A purchased standard with a certified value from ERA was considered the outside standard source. The standards were run at several dilutions, again to validate the range of the curve. A known value of standard was added to the lab's distilled water and then run as a sample. This was done to assure that the concentration of the spiking solution used in the samples was accurate. Turbidity spiking solution and standards were supplied by Hach. Several pre-made, known concentration gels were used as outside QC sources, and a 4000 NTU Hach spiking solution was used in analyzing the samples.

Other data source

Data were also obtained from the monthly report submitted to the Ohio EPA by the Southwest Licking Community Water & Sewer District. Methods were as follows from U.S. EPA (1983): CBOD (405.1); TSS (160.2); Ammonia (350.1); COD (410.4); Nitrate (353.2); TP (365.4); FC (SM_9222D).

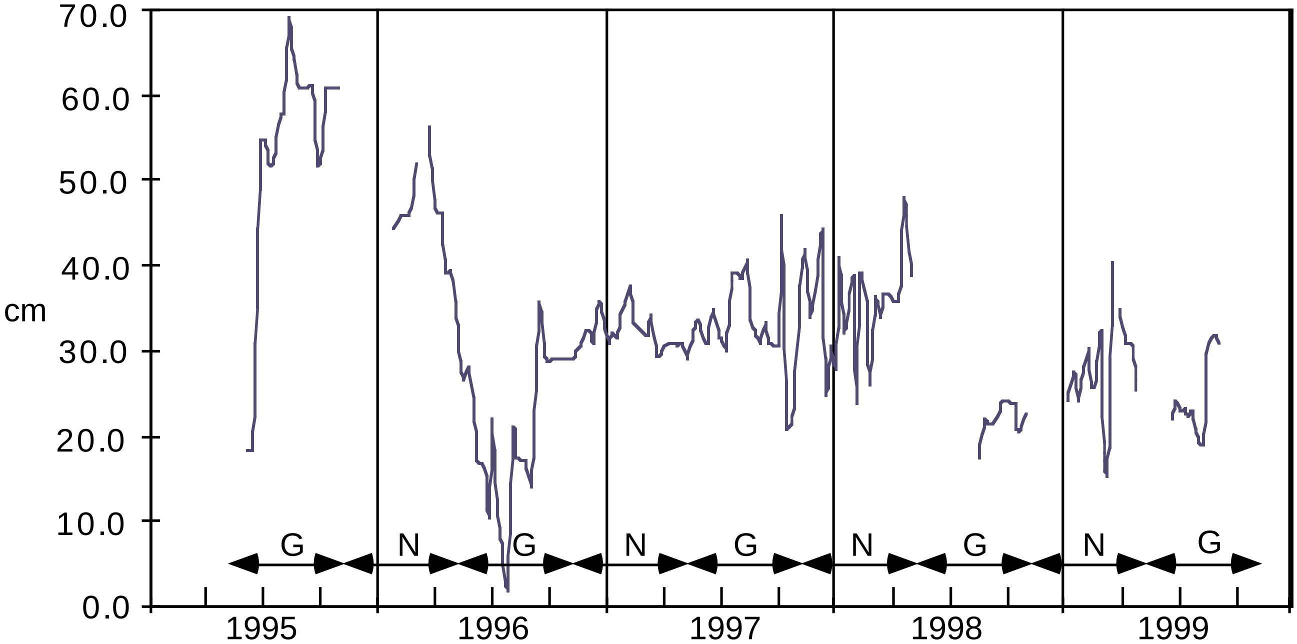

Figure 2. Approximate water depth of Licking County wastewater wetland as measured at the outflow staff gage. Analyses in this study were for four calendar years (1995-98) and for 4 growing seasons (G) and four nongrowing seasons (N) starting in mid-1995. Gaps or low water levels are caused by the following: November 1, 1995-January 21, 1996-no data collected; June 3-Sept 3, 1996-low flow for vegetation establishment; April 29-August 18, 1998-offline for vegetation establishment; Nov 10-Dec 18, 1998-offline for plant maintenance; April 29-June 18, 1999-offline for vegetation establishment

Results and Discussion

Hydrology

Wetland North received inflow almost continuously since the project began in mid-1995 except for shutdowns of about 2 months during summer 1996, three months in 1998, and 2 months in 1999 (Fig. 2). The annual hydraulic loading rate (HLR) of the wetlands ranged from 8.2 to 12.3 cm/day (Fig. 3), almost double the design rate of 5.8 cm/day for the wetland. High loading was due to a more rapid increase in development in the sewer district and due to the loss of one wetland at the site due to excessive seepage (Wetland South was only operated for a short periods in 1996, 1997 and 1998 and then abandoned because of excessive seepage). Average ± std error of water depths ranged from 53 ± 3 cm in 1995 to 29±2 cm in 1996 (Fig. 3).

Retention time of water in the basins ranged from 2.7 to 6.4 days from 1995 through 1998 (Fig. 3). This is shorter than the design retention time of 8.6 days for the same reasons as outlined above for the high HLR. In some cases a rapid retention time resulted from the fact that low water conditions were maintained to stimulate vegetation growth, particularly in 1996.

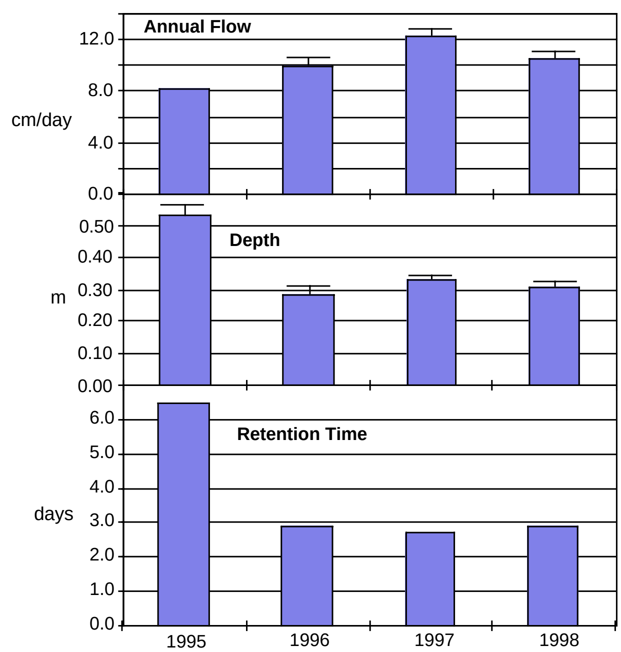

Figure 3. Hydraulic loading rate (HLR), average water depth, and average retention time for Licking County wastewater wetland, 1995-1998.

Water Quality

Average (± std error) changes in water quality in the wastewater wetland over the four-year period (calendar

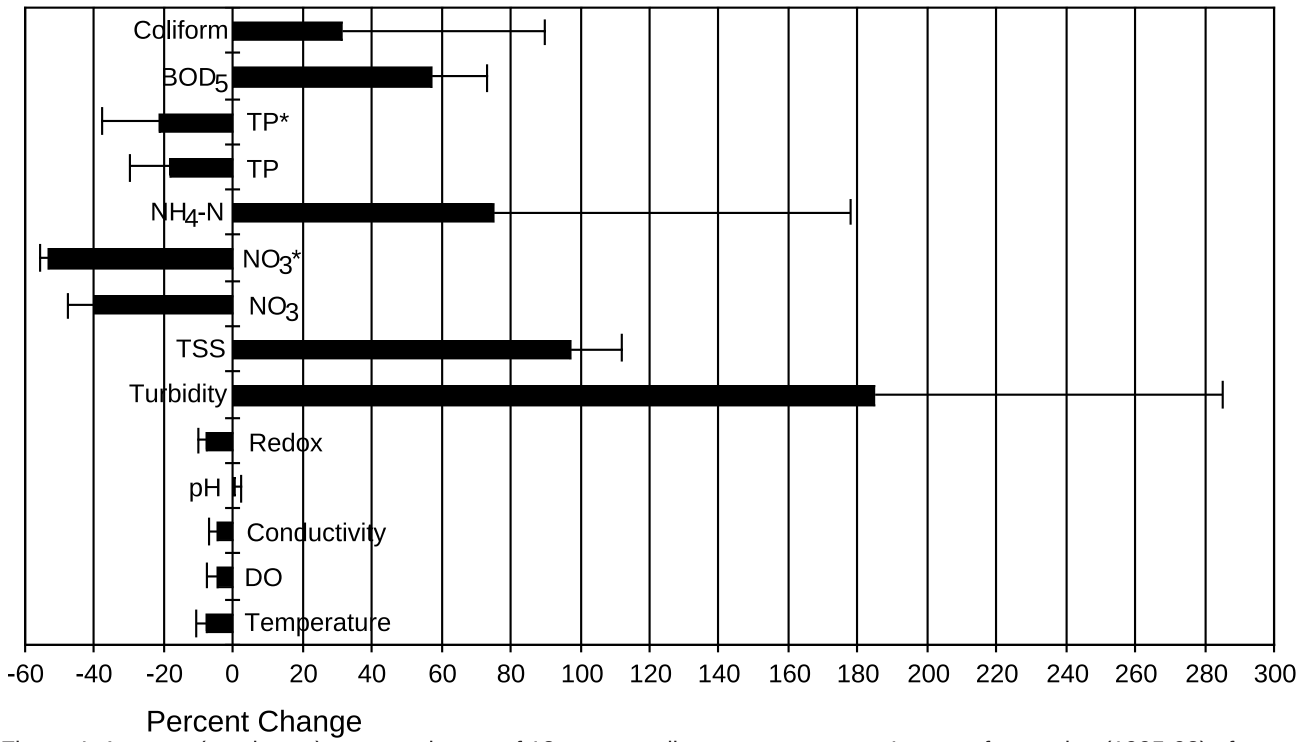

Figure 4. Average (± std error) percent change of 12 water quality parameters over 4 years of operation (1995-98) of Licking County wastewater wetland. * indicates N and P analyses provided by Licking County wastewater reports.

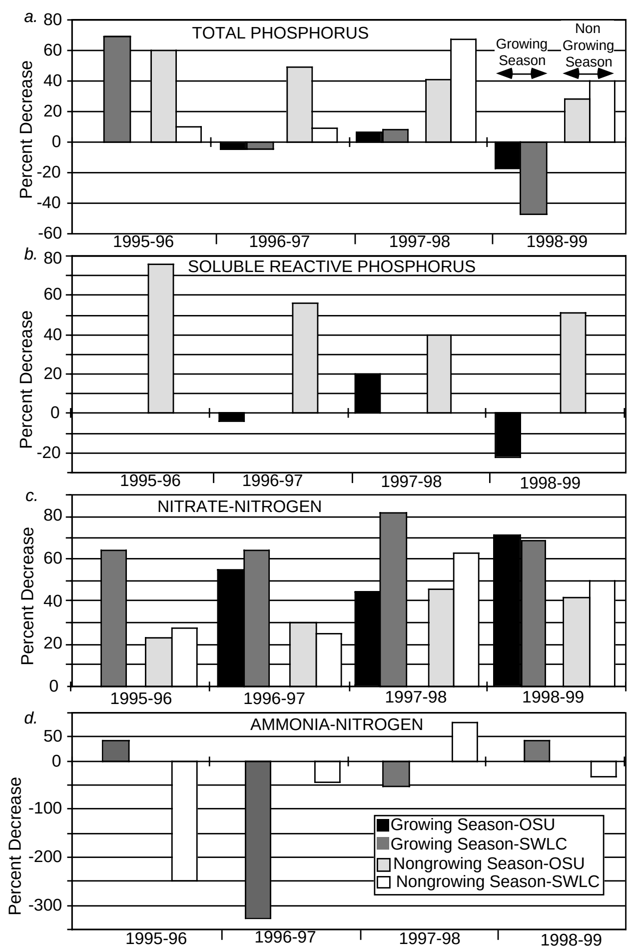

Figure 5. Nutrient retention for growing and nongrowing seasons at Licking County wastewater wetland.

years 1995 through 1998) are summarized in Figure 4. Complete results for annual, growing season, and nongrowing season are listed respectively in Appendices A, B, and C.

Nutrients

The wetland was effective in reducing nitrate over the four-year study period, with measurements from two labs indicating 39±9 and 53±3 percent reduction by concentration (Fig. 4). Nitrate-nitrogen retention appeared to improve annually with retention increasing from 37 in 1996 to 56% in 1998 (OSU data) and 48 to 61% over the same period with SWLC data.

Phosphorus retention was 18±9 and 21±15 with measurements from two laboratories (Fig. 4). Total phosphorus retention decreased from 30 to 23% retention from 1996 to 1998 according to OSU data. The SWLC data showed a 62 % retention in the first year becoming a 4.6% net export by the fourth year.

Ammonia-nitrogen decreased during the first year by 36% and the fourth year by 49% but had dramatic increase of 378% (from 0.11 mg-N/L to 0.53 mg-N/L) in 1996.

Suspended Material

Almost all other parameters besides nutrients showed some decreases in water quality. Total suspended solids almost doubled (from 3-4 mg/L in the inflow to 6 - 9 mg/L in the outflow). Turbidity increased from seasonal averages of 2 - 6 NTU in the inflow to 7 - 13 NTU in the outflow, increasing on average by 185%. It increased 0.9% in 1996 and 334% in 1998.

Organic Matter

Carbonaceous biochemical demand increased by about

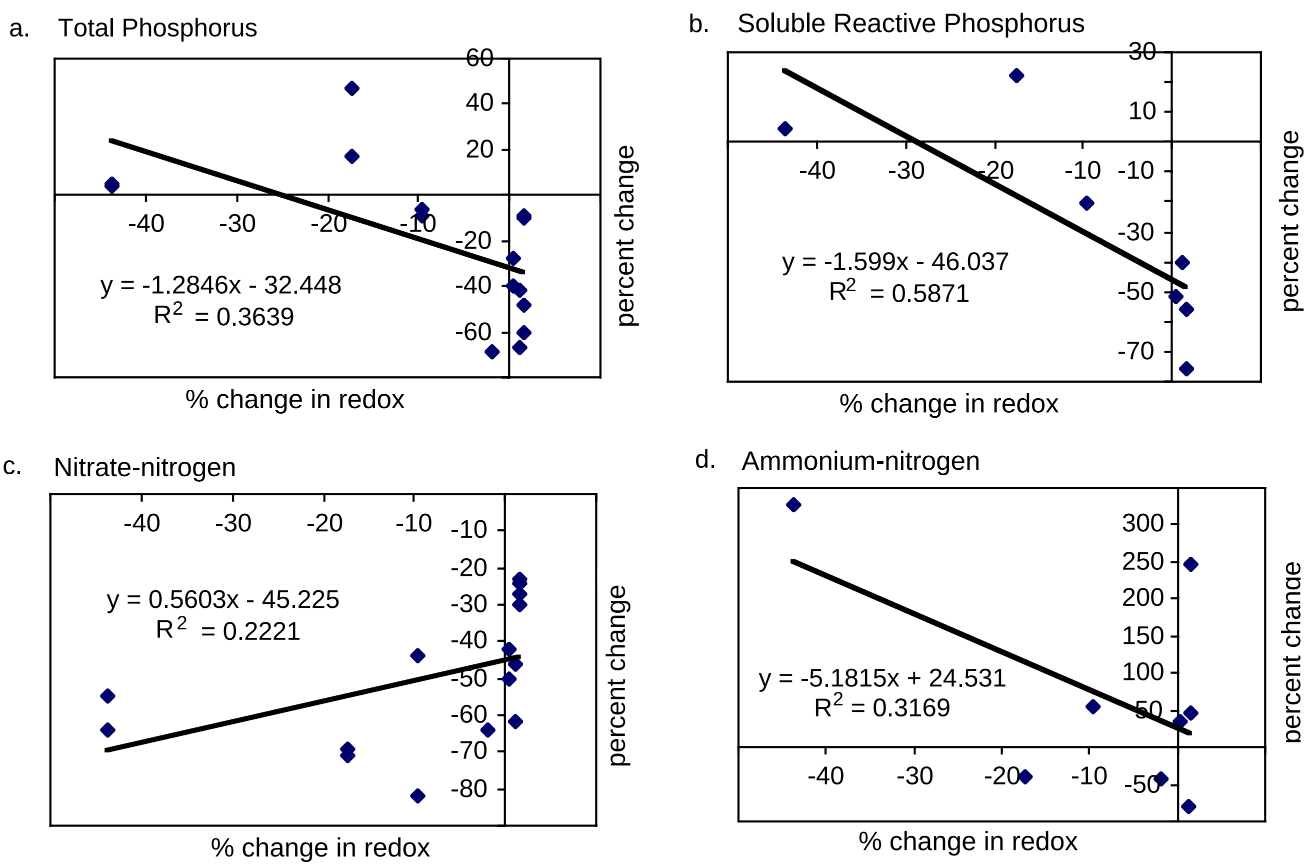

Figure 6. Percent change of a. total phosphrous, b. soluble reactive phosphorus, c. nitrate-nitrogen, and d. ammonium nitrogen as a function of % decrease in redox potential through the wetland.

57% overall, due in part to the exceeding low concentrations coming from the treatment plant (2 mg/L). Average concentrations of the discharge ranged from 2.9 mg/L in 1995 to 4.2 mg/L in 1996, still well below water quality standards.

There was a diminished water quality function of Wetland North in 1996 due to a number of factors. First, a large influx of biosolids occurred in early 1996 causing the development of a largely non-vegetated zone of sludge near the inflow of Wetland North. This has had a noticeable effect on wetland development and water quality. Second, low water levels and thus short retention times were maintained in the summer 1996 for vegetation establishment. Third, the wetland was overloaded hydrologically.

Dissolved Oxygen

Dissolved oxygen was significantly influenced by primary productivity (algal growth) and respiration in the water column of the wetland. Overall, our data showed a decrease in dissolved oxygen of 4.5% (Fig. 4). Average efficiency of algae in the water in capturing solar radiation was 1.5%, a high number for aquatic ecosystems (Mitsch et al., 1997). While readings from our sampling presented here showed little change from inflow to outflow, continuous measurements of oxygen in the basins in 1996 and 1997 showed quite a different picture. Diurnal (day to night) changes of dissolved oxygen of 10 mg/L or more were not uncommon. In late summer 1996 the dissolved oxygen swing became unstable, leading to anaerobic conditions at the outflow and a short period of water quality deterioration. The major causes of this instability were warm summer temperatures, low water levels maintained for vegetation survival, and the overloading of the basin hydrologically and with biosolids. With higher water levels generally maintained in subsequent years, these dramatic decreases of effluent dissolved oxygen were less prevalent.

Growing season effects

There was a marked difference in seasonal patterns of total phosphorus and nitrate-nitrogen retention in the wetlands (Fig. 5). Phosphorus retention in the growing season was generally poor, with exports or almost no retention measured in every year except the first. In the nongrowing season, however, phosphorus retention was consistent in all four years and averaged 31% (SWLC data) to 44% (OSU data). Soluble reactive phosphorus, a relatively high proportion of total phosphorus in most samples, had much the same seasonal pattern as did total phosphorus, with high retention in the winter and no retention to a net export in the growing season (Fig. 5) Nitrate-nitrogen, on the other hand, was retained more during the growing season (57-70% from the two sets of data) than during the nongrowing season (35-41%). This agrees with the analysis by Spieles and Mitsch (2000) who found a statistically

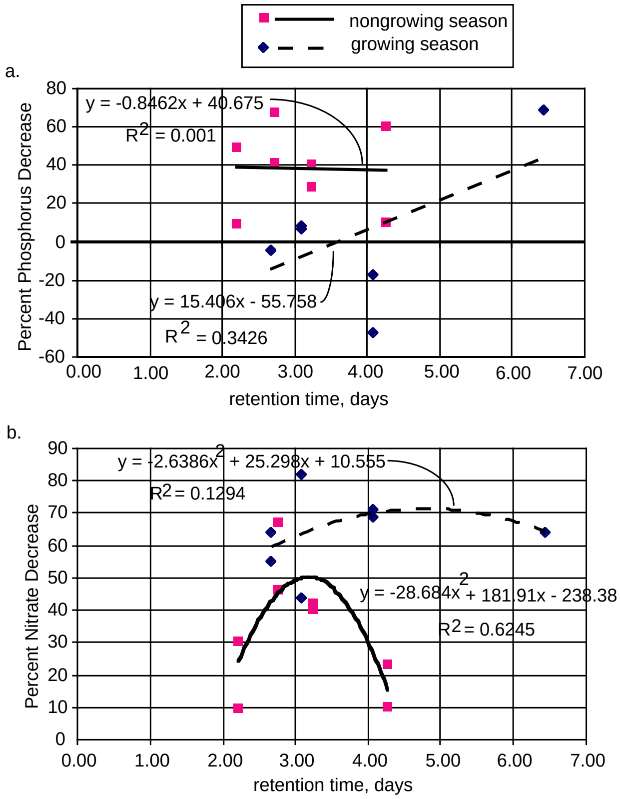

Figure 7. Percent a. phosphorus and b. nitrate-nitrogen retention as a function of wetland retention time.

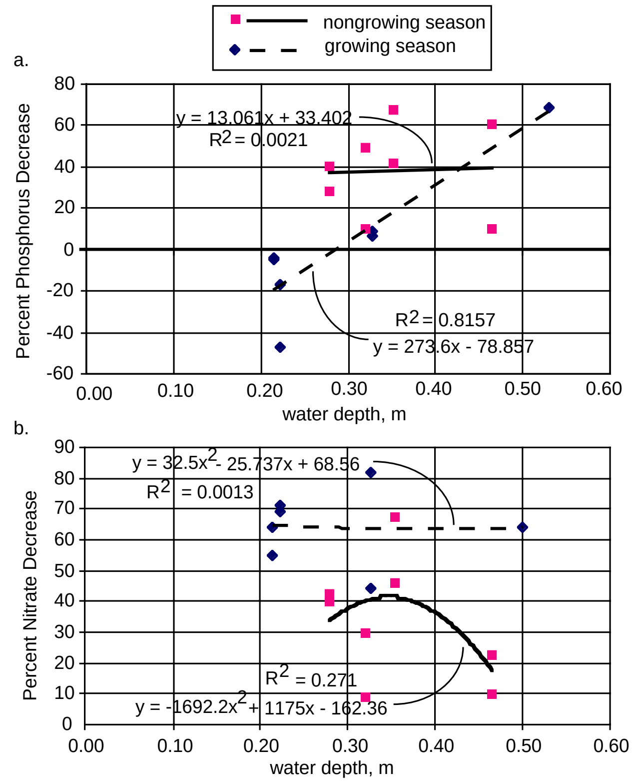

Figure 8. Percent a. phosphorus and b. nitrate-nitrogen retention as a function of wetland average water depth.

greater retention in the warmer growing season than in the cold nongrowing season. Ammonia was exported from the wetlands in half of the growing seasons, particularly in the 1996 growing season, and during three out of the four nongrowing seasons investigated (Fig. 5)

Effects of redox

Redox, as measured at the outflow of the wetland was generally similar to the inflow redox with the notable exception of the 1996 growing season, when it was 44% lower in the outflow. We therefore investigated the effect that change in redox potential through the wetland had on nutrient retention. As expected, the more redox was affected in the wetland, the greater the net export of total phosphorus, soluble reactive phosphorus, and ammonium nitrogen from the wetland (Fig. 6). Conversely, as redox decreased, nitrate nitrogen also decreased through the wetland.

Effect of retention time

Phosphorus retention was higher with greater retention times, but only in the growing season (Fig 7a). There was little correlation between phosphorus retention in the nongrowing season and retention time but the data are distributed over a relatively narrow range of retention times. Nitrate retention seemed to peak at about 3 days retention time and decreased with either shorter or longer retention times in the nongrowing season (Fig. 7b). Results were much less conclusive for the growing season and retention seemed almost independent of retention time.

Effect of water depth

There was a strong relationship between phosphorus retention and water depth in the growing season; the deeper the water, the more the retention (Fig. 8a). The same relationship did not appear for the nongrowing season. Nitrate-nitrogen retention appeared to be generally insensitive to water depth for both the growing and nongrowing season (Fig. 8b) although the nongrowing season showed a slight pattern of less nitrate retention in deeper water.

Conclusions

The southwest Licking County wastewater wetland, as operated from 1995 through 1998, was hydrologically overloaded by a factor of two and its water quality function was thus impaired. Nevertheless, the wetland performed well in retaining nitrate nitrogen, causing an overall reduction of 40 to 50% in this nutrient. Phosphorus retention was more problematic with generally low to no retention in the growing season and significant (30 to 40%) retention in the nongrowing season, probably due to ice cover for some of that period that reduces resuspension. The wetland showed a net export of suspended solids, turbidity, and carbonaceous BOD over the four year period, although discharge concentrations were well below water quality standards. In effect, the wetland is transforming inorganic matter to organic matter, thus taking up inorganic nutrients and exporting internally produced organic matter. When the system goes anaerobic or near anaerobic, as it did on one or two occasions over this 4-year period, phosphorus and ammonia-nitrogen are exported but nitrate-nitrogen retention is enhanced. When water levels were low, as was necessary to stimulate emergent macrophyte growth, phosphorus retention decreased and ammonia and total suspended solids were exported. Probably the most significant variable is retention time. With retention times in this wetland averaging 3 to 6 days and the design criteria of 9 days, it is not surprising that the wetland performance, while somewhat effective in nutrient removal, has been generally less than optimum with other water quality indicators.

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Appendix A. Annual water quality changes, 1995-1998, through Wetland North at Southwest Licking County wastewater treatment facility. Data are presented as average±std error (# samples).

Parameter		1995	1996	1997	1998	1995-98 % Change
OSU DATA						
Temperature, °C	Inflow	16.9±1.5(13)	14.1±0.7(37)(	14.0±0.5(47)	13.9±1.1(32)	
	Outflow	17.6±2.6(13)	12.2±1.2(37)	12.5±1.1(48)	12.4±1.3(27)	
	% Increase	3.7	-13.6	-10.9	-10.4	-7.8±3.9
Dissolved	Inflow	9.9±0.5(13)	9.1±0.4((30)	8.8±0.4(47)	9.1±0.4(32)	
Oxygen, mg/L	Outflow	10.0±1.3(13)	8.1±1.4(27)	9.4±0.9(47)	7.8±1.1(27)	
	% Increase	0.6	-10.2	6.0	-14.5	-4.5±4.7
Conductivity,	Inflow	1927±62(13)	1621±65(34)	1740±46(40)	1696±60(31)	
µS/cm	Outflow	1773±107(13)	1547±61(34)	1683±43(41)	1667±58(26)	
	% Increase	-8.0	-4.6	-3.3	-1.7	-4.4±0.7
pH	Inflow	7.84±0.04(13)	7.71±0.04(36)	7.76±0.08(44)	8.01±0.24(24)	
	Outflow	8.00±0.08 (13)	8.04±0.12(36)	8.17±0.09(44)	7.93±0.26(20)	
	% Increase	2.1	-4.4	5.2	-1.0	+0.5±2.1
Redox,mv	Inflow	343±15(13)	334±16(19)	410±8(40)	358±22(30)	
	Outflow	344±24(13)	257±37(18)	391±12(40)	344±25(25)	
	% Increase	0.3	-22.8	-4.6	-3.9	-7.7±5.1
Turbidity, NTU	Inflow		6.0±2.3(35)	2.2±0.4(52)	3.0±0.4(15)	
	Outflow		6.0±1.6(36)	7.2±1.4(52)	13.1±3.1(16)	
	% Increase		0.9	221	334	+185±98
NO_3-N, mg-N/L	Inflow		14.26±1.74(41)	9.95±0.78(25)	4.64±0.44(30)	
	Outflow		8.97±1.26(44)	7.43±0.59(25)	2.03±0.22(26)	
	% Increase		-37.1	-25.3	-56.2	-39.5±9
SRP, mg-P/L	Inflow		0.96±0.11(35)	0.78±0.09(52)	1.08±0.14(27)	
	Outflow		0.95±0.09(38)	0.62±0.06(52)	0.95±0.14(24)	
	% Increase		-0.8	-21.1	-11.7	-11.2±5.9
TP, mg-P/L	Inflow		1.60±0.32(36)	0.90±0.10(51)	1.26±0.14(29)	
	Outflow		1.11±0.12(37)	0.89±0.11(52)	0.97±0.14(26)	
	% Increase		-30.2	-1.1	-22.8	-18.0±8.7
SWLC DATA						
TSS, mg/L	Inflow	4.2±0.4(65)	4.0±0.2(152)	4.1±0.4(153)	3.0±0.3(92)	
	Outflow	6.4±2.5(20)	8.2±1.9(47)	9.3±2.1(53)	6.0±1.2(29)	
	% Increase	53.9	107	126	103	+97±15
NH_3-N, mg-N/L	Inflow	0.12±0.02(64)	0.11±0.03(150)	0.67±0.15(154)	0.43±0.11(102)	
	Outflow	0.07±0.001(21)	0.53±0.23(50)	0.73±0.25(52)	0.22±0.06(30)	
	% Increase	-36	378	9.3	-49	+75±101
Fecal Coliform,	Inflow	564±154(47)	483±225(74)	1135±365(71)	198±54(48)	
#/100 mL	Outflow	289±231(15)	618±213(25)	602±157(25)	581±191(16)	
	% Increase	-49	28	-47	193	+31±57
$CBOD_5$mg/L	Inflow	1.8±0.1(65)	2.1±0.1(154)	2.4±0.1(155)	2.4±0.1(102)	
	Outflow	2.9±0.5(21)	4.2±0.5(46)	3.1±0.2(53)	3.2±0.3(30)	
	% Increase	63	100	32	35	+57±16
NO_3-N, mg-N/L	Inflow	9.17±0.72(48)	8.07±1.66(96)	2.95±0.14(98)	3.89±0.22(70)	
	Outflow	4.42±0.92(22)	4.22±0.63(44)	1.35±0.18(49)	1.51±0.17(21)	
	% Increase	-52	-48	-54	-61	-53±3
COD, mg/L	Inflow	16.5±1.9(17)	19.2±1.1(48)	28.7±2.0(51)	28.5±2.0(35)	
	Outflow	nd	nd	nd	nd	
	% Increase	nd	nd	nd	nd	
Total P, mg-P/L	Inflow	4.04±1.48(20)	1.19±0.09(47)	1.10±0.19(47)	1.18±0.13(34)	
	Outflow	1.52±0.34(21)	1.14±0.11(45)	0.85±0.08(52)	1.23±0.17(30)	
	% Increase	-62	-4.3	-23	4.6	-21±15
TKN, mg-N/L	Inflow	0.88±0.22(5)	1.05±0.18(12)	1.56±0.24(11)	2.45±1.13(8)	
	Outflow	nd	nd	nd	nd	
	% Increase	nd	nd	nd	nd	

Appendix B. Water quality changes in growing season, April 1995-Oct 1998, through Wetland North at Southwest Licking County wastewater treatment facility. Growing season assumed to be May 1 through October 30. Data are presented as average±std error (# samples).

Parameter		1995 Growing Season	1996 Growing Season	1997 Growing Season	1998 Growing Season	1995-98 % Change
OSU DATA						
Temperature, °C	Inflow	19.7±0.7(9)	17.5±0.7(19)	17.0±0.5(24)	19.1±0.3(15)	
	Outflow	22.4±1.7(9)	18.3±0.8(18)	18.9±0.9(25)	18.3±1.5(10)	
	% Increase	13.6	4.5	11.2	-4.0	+6.3±3.9
Dissolved	Inflow	9.3±0.5(9)	8.1±0.4(16)	8.1±0.4(24)	8.1±0.4(15)	
Oxygen, mg/L	Outflow	8.9±1.7(9)	5.7±2.3(13)	6.7±0.9(24)	1.7±0.3(10)	
	% Increase	-4.7	-30.6	-18.0	-79.5	-33±16
Conductivity,	Inflow	1900±81(9)	1649±99(19)	1729±59(21)	1962±52(15)	
µS/cm	Outflow	1688±146(9)	1612±101(18)	1690±70(22)	1922±82(10)	
	% Increase	-11.2	-2.2	-2.2	-2.0	-4.4±2.3
pH	Inflow	7.89±0.04(9)	7.70±0.05(19)	7.87±0.11(22)	8.34±0.25(14)	
	Outflow	7.99±0.11	7.87±0.18(18)	8.27±0.11(23)	8.12±0.24(10)	
	% Increase	1.3	2.1	5.0	-2.7	+1.4±1.6
Redox,mv	Inflow	342±20(9)	308±20(12)	411±10(21)	322±40(15)	
	Outflow	336±34(9)	173±49(10)	372±19(21)	266±49(10)	
	% Increase	-1.8	-43.6	-9.5	-17.4	-18±9
Turbidity, NTU	Inflow		2.1±0.3(18)	2.3±0.6(26)		
	Outflow		8.7±3.1(18)	5.9±1.4(26)		
	% Increase		319	155		+237±82
NO_3-N, mg-N/L	Inflow		9.04±0.78(24)	7.65±1.26(8)	4.90±0.64(14)	
	Outflow		4.04±0.54(24)	4.28±0.43(8)	1.44±0.30(10)	
	% Increase		-55	-44	-71	-57±8
SRP, mg-P/L	Inflow		0.97±0.14(19)	0.64±0.11(26)	1.27±0.12(15)	
	Outflow		1.01±0.13(19)	0.51±0.09(26)	1.56±0.13(11)	
	% Increase		4.1	-20.4	22.4	+2.0±12.4
TP, mg-P/L	Inflow		1.18±0.15(19)	0.69±0.11(25)	1.41±0.15(15)	
	Outflow		1.23±0.20(19)	0.65±-0.09(26)	1.66±0.20(10)	
	% Increase		4.1	-6.7	17.2	+4.9±6.9
SWLC DATA						
TSS, mg/L	Inflow	4.4±0.4(52)	3.2±0.3(77)	4.4±0.4(77)	2.2±0.5(37)	
	Outflow	6.5±3.4(15)	4.0±0.6(25)	14.0±4.9(26)	3.5±0.7(15)	
	% Increase	47.2	28	216	54	+86±44
NH_3-N, mg-N/L	Inflow	0.12±0.02(51)	0.09±0.05(73)	0.81±0.18(77)	0.60±0.22(47)	
	Outflow	0.07±0.01(16)	0.39±0.07(27)	1.25±0.47(26)	0.36±0.11(16)	
	% Increase	-42	327	54	-41	+74±87
Fecal Coliform,	Inflow	564±154(47)	342±208(72)	1148±370(70)	198±54(48)	
#/100 mL	Outflow	289±231(15)	639±221(24)	602±157(25)	581±191(16)	
	% Increase	-49	87	-48	193	+46±58
$CBOD_5$mg/L	Inflow	1.8±0.1(52)	1.5±0.1(77)	2.16±0.11(76)	2.0±0.1(47)	
	Outflow	1.9±0.2(16)	3.4±0.5(27)	3.0±0.3(26)	3.19±0.40(16)	
	% Increase	6.0	127	41	61	+59±25
NO_3-N, mg-N/L	Inflow	7.84±0.62(39)	5.16±0.67(47)	2.33±0.19(47)	4.01±0.34(33)	
	Outflow	2.84±0.70(16)	1.85±0.84(20)	0.43±0.13(22)	1.26±0.23(9)	
	% Increase	-64	-64	-82	-69	+70±4
COD, mg/L	Inflow	15.8±1.9(16)	19.7±1.2(27)	30.8±3.6(25)	31.1±3.7(16)	
	Outflow	nd	nd	nd	nd	
	% Increase	nd	nd	nd	nd	
Total P, mg-P/L	Inflow	4.38±1.86(16)	1.16±0.11(27)	0.80±0.11(26)	1.33±0.16(16)	
	Outflow	1.37±0.43(16)	1.21±0.17(25)	0.73±0.08(17)	1.96±0.17(16)	
	% Increase	-69	4.7	-8.6	47	-6.5±24
TKN, mg-N/L	Inflow	0.85±0.29(4)	1.03±0.31(6)	1.32±0.34(6)	3.61±2.24(4)	
	Outflow	nd	nd	nd	nd	
	% Increase	nd	nd	nd	nd	

Appendix C. Water quality changes in non-growing season, Nov 1995-Apr 1999, through Wetland North at Southwest Licking County wastewater treatment facility. Nongrowing season assumed to be November 1 through March 31. Data are presented as average±std error (# samples).

Parameter		1996 Nongrowing	1997 Nongrowing	1998 Nongrowing	1999 Nongrowing	1996-99 % Change
OSU DATA						
Temperature, °C	Inflow	9.7±0.7(15)	10.8±0.3(21)	10.2±0.8(25)	11.8±0.4(13)	
	Outflow	6.1±1.1(14)	5.4±0.7(19)	7.5±1.1(25)	8.5±1.3(13)	
	% Increase	-36.4	-50.4	-26.7	-27.9	-35±5
Dissolved Oxygen, mg/L	Inflow	10.2±0.6(11)	11.3±0.6(21)	9.4±0.4(25)	8.3±1.1(14)	
	Outflow	14.5±1.3(9)	11.6±1.7(19)	10.6±0.7(25)	9.3±1.6(14)	
	% Increase	41.4	2.7	12.8	11.5	+17±8
Conductivity, µS/cm	Inflow	1703±83(15)	1115±241(17)	1484±36(24)	1297±78(13)	
	Outflow	1619±89(14)	1075±237(15)	1499±24(24)	1253±107(13)	
	% Increase	-4.9	-3.6	1.0	-3.3	-2.7±1.3
pH	Inflow	7.72±0.09(14)	9.39±0.55(20)	7.57±0.24(18)	7.54±0.06(14)	
	Outflow	8.45±0.14(13)	7.06±0.53(18)	7.74±0.29(17)	8.11±0.13(14)	
	% Increase	9.5	-24.8	2.2	7.5	-1.4±7.9
Redox,mv	Inflow	346±15(8)	258±52(17)	384±6(23)	235±29(12)	
	Outflow	351±18(7)	262±57(15)	389±9(23)	236±32(12)	
	% Increase	1.6	1.6	1.2	0.4	+1.2±0.1
Turbidity, NTU	Inflow	16.3±7.3(10)	4.7±1.0(24)	3.2±0.7(24)		
	Outflow	3.4±0.5(9)	3.1±0.4(22)	15.5±2.7(25)		
	% Increase	-79	-33	389		+92±149
NO_3-N, mg-N/L	Inflow	25.96±4.1(11)	11.46±0.65(24)	4.19±0.44(24)	4.77±0.61(18)	
	Outflow	19.9±2.3	7.99±0.62(22)	2.24±0.20(25)	2.77±0.66(15)	
	% Increase	-23.3	-30.3	-46.5	-42.0	-35.5±2.6
SRP, mg-P/L	Inflow	3.42±1.31(15)	4.33±1.10(24)	0.76±0.20(20)	0.96±0.19(18)	
	Outflow	0.82±0.18(11)	1.91±0.47(22)	0.46±0.08(22)	0.47±0.10(16)	
	% Increase	-76	-55.8	-40.1	-51.4	-55.8±3.7
TP, mg-P/L	Inflow	2.26±0.99(11)	4.53±1.08(24)	0.99±0.18(23)	0.57±0.14(14)	
	Outflow	0.91±0.20(10)	2.32±0.46(22)	0.58±0.07(25)	0.41±0.08	
	% Increase	-60	-48.7	-41.3	-27.9	-44.5±6.7
SWLC DATA						
TSS, mg/L	Inflow	5.1±0.4(64)	3.3±0.3(75)	3.9±0.6(75)	4.7±0.5(44)	
	Outflow	7.8±1.7(29)	8.0±3.1(25)	6.0±1.1(21)	11.4±4.2(16)	
	% Increase	55	143	52	142	+95±26
NH_3-N, mg-N/L	Inflow	0.15±0.06(66)	0.19±0.06(76)	0.62±0.24(75)	0.46±0.10(49)	
	Outflow	0.52±0.39(29)	0.27±0.11(25)	0.13±0.05(21)	0.62±0.16(34)	
	% Increase	248	45	-79	34	62±68
Fecal Coliform, #/100 mL	Inflow	8700±1117(24)	260(1)	nd	nd	
	Outflow	118(1)	nd	nd	nd	
	% Increase	-99	nd	nd	nd	
$CBOD_5$mg/L	Inflow	2.6±0.1(66)	2.4±0.1(78)	2.8±0.2(75)	3.6±0.3(48)	
	Outflow	3.9±0.7(25)	3.19±0.35(26)	3.4±0.3(21)	3.9±0.3	
	% Increase	49	33	21	6.3	+27±9
NO_3-N, mg-N/L	Inflow	12.83±3.58(43)	4.91±0.40(51)	3.50±0.24(49)	5.45±0.38(38)	
	Outflow	9.32±1.22(25)	3.73±0.45(26)	1.32±0.18(19)	2.71±0.41(16)	
	% Increase	-27	-24	-62	-50	-41±9.1
COD, mg/L	Inflow	14.7±0.9(35)	25.9±1.5(26)	25.4±1.5(25)	28.2±3.2(19)	
	Outflow	nd	nd	nd	nd	
	% Increase	nd	nd	nd	nd	
Total P, mg-P/L	Inflow	1.40±0.24(17)	1.40±0.16(21)	1.34±0.35(24)	1.21±0.26(17)	
	Outflow	1.26±0.25(16)	1.27±0.12	0.44±0.08(21)	0.72±0.11(17)	
	% Increase	-10	-9.4	-67	-40	-31.6±13.8
TKN, mg-N/L	Inflow	1.20±0.20(5)	1.62±0.45(5)	1.29±0.15(6)	1.62±0.55(6)	
	Outflow	1.00(1)	nd	nd	nd	
	% Increase	-17	nd	nd	nd	